

Near Shore Wave Processes

Edward B. Thornton
Oceanography Department
Naval Postgraduate School
Monterey, CA 93943-5000
phone: (831) 656-2847 fax: (831) 656-2712 email: thornton@nps.navy.mil

Timothy P. Stanton
phone: (831) 656-3144 email: stanton@oc.nps.navy.mil
Award #'s: N0001401WR20023; N0001401WR20021
<http://www.oc.nps.navy.mil/~thornton/>
<http://www.oc.nps.navy.mil/~stanton/>
<http://www.frf.usace.army.mil/SandyDuck/SandyDuck.stm>

LONG-TERM GOALS

Long-term goals are to predict the wave-induced three-dimensional velocity field and induced sediment transport over arbitrary bathymetry in the near shore given the offshore wave conditions.

OBJECTIVES

The interrelationship of wave-induced hydrodynamic and sediment processes over the vertical and morphologic processes at the bed are measured and modeled. The primary mechanism for changes in moment flux that drive near shore hydrodynamics is due to the dissipation by breaking waves, the processes of which are poorly understood. To improve our understanding of breaking waves, the dissipation associated with bubble injection is measured along with the velocity fields over the vertical. Bottom boundary layer measurements are obtained to determine bottom stress and dissipation. Sediment transport is measured in response to the measured mean longshore and cross-shore currents, wave velocities and induced stresses. The small-scale morphology, which acts as hydraulic roughness for the mean flows and perturbs the velocity-sediment fields, is measured as a function of time and over large areas to examine cross-shore and alongshore variation.

APPROACH

A comprehensive six-week experiment was conducted during April/May 2001 at Sand City, California, to measure processes on a steep beach. It is hypothesized that the plunging and collapsing/surging breaking wave processes occurring on a steep beach are significantly different than plunging/spilling breaking wave processes previously measured at Duck over a moderately sloping bar. Wave reflection can be significant on steep beaches. It is further hypothesized that the radiation stresses are modified by reflected waves owing to modulation of the water depth and the kinematics of the breaking waves steepened by the superimposed reflected wave energy. The effects of reflected wave energy on sediment transport is being studied with high resolution BCDVSP profiles of sediment flux and velocity over 50cm range above the bed. The modulation of the breaker location can then modify the dynamics of the nearshore, such as wave set-up and undertow.

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The comprehensive Delft3D morphodynamic model developed by Delft Hydraulics is being assessed by comparing with field data. In addition, process models for breaking waves, momentum mixing due to the interaction of longshore and cross-shore vertical mean profiles, and bottom shear stress enhanced by the form drag of bedforms and by turbulence of wave breaking are compared with observations. Both linear and nonlinear (Boussinesq) wave models are considered.

WORK COMPLETED

SteepBeach Experiment. An unexpectedly large variation in incident waves occurred during the experiment owing to a series of storms, resulting in waves up to 4 m at breaking. The Steep Beach Experiment was designed to test instrumentation and techniques to be used in NCEX, and to examine processes on a steep beach (high Iribarren number) where reflection is important. The large-scale morphology is a barred shoreline cut by rip channels spaced 100-200 m apart. Offshore of the bar the slope is 1:20, and the beach slope is steep at 1:5. Comprehensive wave and current data have not been obtained previously on a steep beach, and these data greatly expand the range of measured beach processes. Objectives of the Steep Beach experiment were to measure wave transformation, reflection and set-up/down, breaking wave and current-induced turbulent bottom and surface boundary layers, and sediment flux in the surf zone. Data selected for analysis are from a cross-shore array of wave and current sensors that bisected the shoal between rip channels. Measurements include vertical profiles of horizontal velocity with 8 em sensors, and void fraction (bubble content) with 12 conductivity cells, and surface elevation with surface piercing wave staff and co-located pressure sensors. Bottom boundary layer observations included small-scale morphology measured by an x-y scanning altimeter, and turbulence and sediment concentration profiles measured with a Bistatic Coherent Doppler Velocity and Sediment Profiler (BCDVSP) (Stanton 1996, 2001). Directional wave spectra were measured by an offshore buoy in 18 m water depth. The 2 m spring tidal range caused the surf zone to sweep past the fixed tower measurement location over a tidal cycle, so that the vertical profile of the entire surf zone was measured over tidal cycles. Bathymetry of the measurement area was surveyed during the experiment using an instrumented jetski (Jamie MacMahan, University of Florida). The beach was surveyed using DPGS mounted on a wader for the shoal areas and on a motorized vehicle (Gator) at low tide to overlap the jetski survey region. Surface elevation measurement techniques of breaking waves are being intercompared at the central array using, a surface piercing wave-wire, and a LIDAR at a fixed point. The cross-shore array was configured to form reflection measurement arrays for the waves reflecting off the beach and off the bar. Wave reflection varied with the tide. At low tide the incident waves were dissipative. At approximately mean tide and higher, waves reflected off the steep beach face resulted in obvious nodes in spectra, even at the sea-swell wave band, indicating strong reflection. Reflection coefficients are being determined as a function of the tide stage. Preliminary results of the experiment can be found at <http://www.oc.nps.navy.mil/ripex/>.

The Delft3D nearshore hydrodynamic model was assessed by comparing model output with data from comprehensive nearshore NSTS and Duck field experiments, which include observations from barred and planar beaches and a wide range of conditions with maximum mean currents of 1.5 m/s.

RESULTS

The Delft3D model has two free parameters, a depth dependent breaking term, γ , and the bed roughness length, k_s , in the White-Colebrook formulation for bottom shear stress. The calibration formula developed by Battjes and Stive (1985) to determine the breaking wave dissipation parameter γ as a function of the deep water wave steepness, s_0 , in the Battjes and Janssen (1978) wave transformation model was verified. Good comparisons of the predicted and measured H_{rms} values were obtained on both barred and planar beaches using γ from Battjes and Stive (1985) for $s_0 > 0.002$. For $s_0 < 0.002$, γ was found independent of s_0 , and a new parameterization for γ was introduced based on the Iribarren number, which includes the beach slope. Improved H_{rms} predictions were obtained using the γ formulation based on the Iribarren number for $s_0 < 0.002$, with overall model rms error $< 8\%$.

A bed shear stress formulation in which k_s represented a measurable quantity was sought. Values for k_s that provided a computed best fit to mean current observations for the entire data sets were $k_s = 0.003$ m for the barred beach and $k_s = 0.009$ m for the planar beach. However, these values do not correspond to either the measured bed roughness height, $O(0.04)$, or the sediment grain size, $O(0.0002$ m). Tests indicate that model predictions are not sensitive to order of magnitude variations in k_s . Using the best fit k_s suggests that the cross-shore variation of c_f is not overly sensitive to changes in k_s , and is mostly controlled by depth changes associated with tidal variation.

The inclusion of the roller was needed to properly model the magnitude of the cross-shore distribution of the alongshore current. Including rollers in the wave forcing results in significantly improved predictions of the observed alongshore current structure by shifting the predicted velocity maxima shoreward and increasing the velocity in the trough of the bar compared with model predictions without rollers. On near-planar beaches and high-energy events on barred beaches, a 1-D (alongshore uniform bathymetry) model performs as well as 2-D. On barred beaches under moderate conditions when alongshore non-uniform bathymetry prevails, the 2-D model performs better than the 1-D model, particularly in the bar-trough region. Wave forcing balances the bottom stress with a second balance between alongshore variation in the mean surface elevation (pressure gradients) and the inertia of the alongshore current. An example of the mean currents over an alongshore inhomogeneous, barred beach is shown in Figure 1. Using the classic 1-D alongshore current model for this data results in two maxima over the bar and at the beach (see for example Church and Thornton, 1995). Applying the 2-D model, the mean alongshore currents at the measurement array compare well as the result of including alongshore pressure gradients (middle panel, Fig. 1). Paradoxically, the currents to the south show 2 maxima, which are the result of the local pressure gradients.

IMPACT/APPLICATIONS

On the basis of Delft3D hydrodynamic model comparisons with comprehensive nearshore field data acquired over two decades funded in all or part by ONR, it is recommended the U.S. Navy adopt Delft3D as an operational surf model.

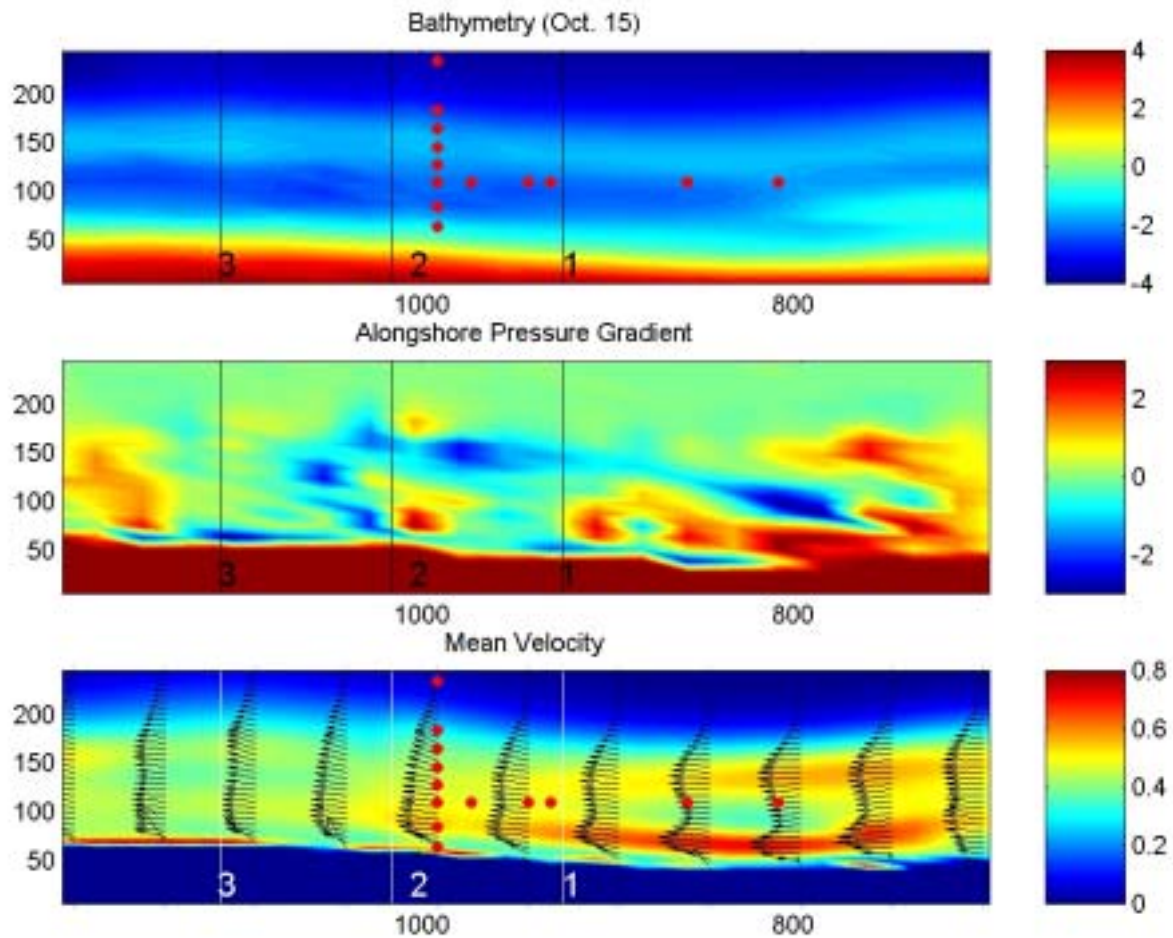


Figure 1. Delft3D model comparisons with observations during Delilah experiment at Duck, N.C. on Oct. 15, low tide. Top panel: Bathymetry overlaid with H_{rms} predicted contours (magnitude in meters). Middle panel: model computed pressure gradients at low tide (shaded background in N/m). The red shades represent positive pressure gradients that act in the direction of wave forcing (right to left). Darker blue shades are negative pressure gradients that act left to right. Bottom panel: Mean (1 hour) velocities. The shaded background represents velocity magnitude in m/s. The red circles are measurement locations

TRANSITIONS

It is recommended on the basis of comparisons with comprehensive nearshore field data that the Delft3D hydrodynamics model be modified to include roller dynamics and then be adopted by the U.S. Navy as an operational surf model.

RELATED PROJECTS

1. Results of process modeling obtained on this project are being applied to nearshore modeling efforts

under the following programs: Surf Model (ONR), Modeling Wave Dissipation within the Wave Boundary Layer (ONR), and Development and Verification of a Comprehensive Community Model for Physical Processes in the Nearshore (NOPP).

2. Collaborative modeling and data comparisons of breaking waves using Boussinesq equations is being performed by PhD students at the U of Quebec under co-direction with Barbara Boczar-Karakiewicz.

3. Collaborative 2D modeling of BBL turbulence and sediment suspension using the DUNE2D model with Dianne Foster at Ohio State University.

4. Collaborative modeling of BBL flow and near-bed stresses using a 3 D hybrid LES model with Emily Zedler and Bob Street at Stanford University.

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